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RADIOASTRONOMICAL OBSERVATIONS OF THE SOLAR ECLIPSE OF 31 JULY 1963 IN CENTIMETER WAVELENGTHS *

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SUMMARY

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This paper presents the first results of radioastronomical observations of the solar eclipse of 21 July 1963 in the centimeter band. It is found, that the Sun's radiodiameter, determined by the contacts II and III in the 2 to 10 cm wavelength range is little dependent on wavelength. The spectrum of the radio emission source situated above a small group of sunspots had a maximum in the 3.2 — 10 cm region. Comparison is made with measurements of the same source with the aid of radiotelescopes of high resolution carried out in USSR, Japan and USA, corroborating the above findings.

* * *

AUTHOR

The radioastronomical observations under consideration were carried out by a complex expedition of the Astronomical Observatory and of the Chair of Astrophysics of the Leningrad University, alongside with the Radiophysical Institute at Gor'kiy University and the Far-Eastern University, the Main Astronomical Observatory and the Astrophysical Observatory of Shemakhinskaya. The expedition's observation area was situated on the Simushir Island at a distance of 19 ± 1 km from the central line of eclipse at the altitude of 51 ± 1 meters above sea level.

* RADIOASTRONOMICHESKIYE NABLYUDENIYA SOLNECHNOGO ZATMENIYA 21 IYULYA 1963 G V SANTIMETROVOM DIAPAZONE VOLN.

Observations of the moments of time II and III of lunar and solar disk contacts with the view of finding the region of rapid variation of solar atmosphere characteristics were amongst the problems of the expedition, and so were the measurements of residual radiation fluxes at maximum covering of the Sun. The determination of characteristics of the radio emission sources that might be located on the Sun at time of observations constitutes an additional problem.

Alongside with astronomical observation measurements of Earth's atmosphere natural radiation, necessary for accounting the absorption were also conducted; this is essential at small angles above the horizon, at which the Sun was found during eclipse.

ECLIPSE CONDITIONS

The ratio of Moon's and Sun's visible radii was

$$\frac{r_☾}{r_\odot} = \eta = 1.01.$$

The width of the total eclipse band reached 72 km. The position angles of contacts (P) and the heights of the Sun above the horizon (H) are compiled in Table 1.

TABLE 1

contact	P, deg.	H, deg
I	301	− 0.16
II	119	~8
III	299	
IV	120	~17

The minimum distance between the centers of the disks was 7 angular seconds.

The solar activity was characterized by the following figures : the sunspot group area, expressed in millions of fractions of Sun's hemisphere (S_p) was 11 for the group No. 75 (3 spots, with an area 5 for the biggest) and 20 for the group No. 76 (3 spots, with an area of 12 for the biggest). Neither on the eve, nor on the following day of observation has the area of the group No. 75 exceeded 60. The group No. 76 existed only two days: on the 21st and 22nd July. Each group was located inside flocculi of indexes 2 and 3, respectively. The magnetic field of group No. 75 constituted 1800 oe (N), that of group No. 76 – 1800 oe (N) and 2000 oe (S).

A P P A R A T U S

During the time of observations the registration of Sun's radio emission flux took place in the following wavelengths : 2 cm, 3.2 cm, 4.5 cm, 10 cm. The characteristics of the radiotelescopes utilized are compiled in Table 2 hereafter :

TABLE 2

№	λ, см	D, м	2θ, град	τ, сек	ΔT, °K	$T_{\odot}$, °K
1	2,0	3,0	1,0	1,0	20	1100
2	3,2	1,2	2,0	1,0	6	390
1	4,5	3,0	1,0	1,0	6	1850
3	10,0	2,5	3,0	1,5	8	550

N. B.- D is the diameter of the paraboloid; 2θ is the width of the main antenna lobe by "half-power" level; τ is the time constant; ΔT is the fluctuation path of the registration between the deflection maxima; $T_{\odot}$ is the effective antenna temperature at radiotelescope guiding toward the open Sun (upon taking account of atmosphere effect).

The calibration of the radiotelescopes was made by comparing the emissions of cold and hot absorbers, and also by way of comparison of cold absorber's emission with the space in the direction of zenith.

Influence of the Earth's Atmosphere on the Results of Observations

The small Sun's height above the horizon during observation time conditioned the strong refraction, absorption and natural emission of terrestrial atmosphere effects on the results of observation.

The refraction was determined by the mean data for a standard atmosphere.

In order to take into account the absorption, special measurements of Earth's atmosphere natural emission were conducted directly prior to the beginning of eclipse observation and immediately after the end at heights of 0; 2; 4; 6; 8; 10; 12 and 15°.

The temperatures of atmosphere emission, obtained in both cases at all indicated angles, practically coincided. The utilization of these data allowed the determination of the absorption coefficient of Sun's radio emission flux $\gamma(H)$ for any angle of the spot by the formula

$$\gamma(H) = \frac{T_a(H)}{T_0 - 32},$$

where T_a is the antenna "temperature"; T_0 is the temperature of the air at the ground [2] (at time of observation $T_0 = 280^\circ K$). The values of $\gamma(H)$ thus determined for the time of eclipse's total phase ($H = 8^\circ$) and various wavelengths, are compiled in Table 3 hereafter :

TABLE 3

λ, см	3,2	4,5	10,0
$T_a(H_0)$, °K $\gamma(H_0)$	25±3 0,1±0,010	24±4 0,1±0,015	20±4 0,08±0,002

The above-compiled coefficients $\gamma(H_0)$ were subsequently utilized for computing the residual fluxes of Sun's radio emission.

When comparing the registration of that flux in $\lambda = 3.2$ cm and $\lambda = 10$ cm, strong fluctuations of the flux, taking place simultaneously in both wavelengths, were revealed between contacts I and II. - These fluctuations had a characteristic variation time of the order of 2— 4 min. Their amplitude did not depend on either the antenna dimensions or the wavelength, and it dropped at the increase of Sun's height, constituting 10 and 3 percent of the total Sun's radio emission flux respectively for $H = 3$ and 6°. No fluctuations were observed when H exceeded 7°.

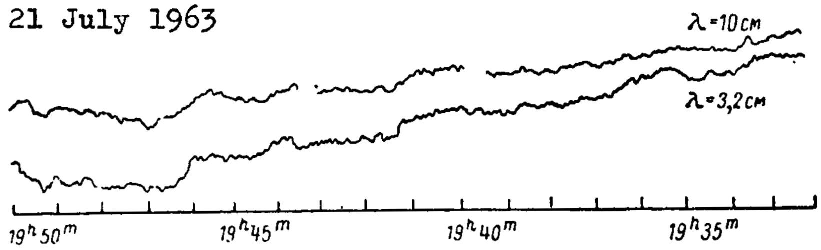

Fig. 1

Plotted in Fig. 1 are the portions of fluctuation registration in the wavelengths of 3.2 and 10 cm. Observations at $\lambda = 2$ cm and $\lambda = 4.5$ cm. begun later, have shown that fluctuations correlate in all wavelengths.

It should be noted that the registrations of atmosphere's natural radiation, conducted prior and after eclipse, just as in the course of a few following days, did not reveal fluctuations of such character, even for small H.

Analogous phenomena were already noted in the work [3], when synchronous fluctuations were observed in $\lambda = 10$ cm and $\lambda = 23$ cm during the solar eclipse of 2 October 1959 for $H \leqslant 4^{o}$.

RESULTS OF OBSERVATIONS

The processing of the results of eclipse observation allowed the determination of the following quantities : a) the moments of time of optical contacts, B) the moments of time of radiocontacts, c) the residual fluxes of concealed Sun's emission, d) certain characteristics of the radio emission source, situated in the visible Sun's hemisphere.

a) Moments of Time of Optical Contacts

The second and third moments of time of optical contacts $t_{II\,0}$ and $t_{III\,0}$ were determined visually. Comparison of indications by the then utilized timer associated with main service chronometer, gave the following results :

$$t_{II\,0} = 19^h15^m06{,}^s8 \pm 0{,}^s1 \;\; U.\; T.,$$
$$t_{III\,0} = 19^h15^m44{,}^s8 \pm 0{,}^s2 \;\; U.\; T.$$

b) Moments of Time of Radiocontacts

The moments of time of the second and third radiocontacts $t_{II\,p}$ and $t_{III\,p}$ were determined directly by the registration of radio emission flux variation during eclipse. The results of such determinations are compiled in Table 4, where the time differences between optical and radiocontacts are also included. The principal part of errors of measurements is due to registration line fluctuations, caused by noises from the devices. The influence of terrestrial atmosphere upon these measurements was practically nil, since contacts occurred at sufficient heights of the Sun, $\sim 8^{o}$. For clarity, the portions of registrations near the contacts, and the annotations of boundaries of the values t_p placed in the Table 4, are plotted in Fig. 2. The differences Δt, brought out in the table, allow, for a known relative angular motion velocities of the solar and lunar disks, to find the Sun's radioradius – r_p. If the relative motion velocity is determined by well known values of η and by the time difference between the second and third optical contacts – Δt_o, we shall have

$$\frac{r_p}{r_\odot} = 1 + \frac{2\Delta t^*}{\Delta t_0} |\eta - 1| - \Delta,$$

where Δ is the correction due to disposition of expedition's observation area on the side from the central line of eclipse.

At the chosen method of determination of the relative angular velocity and distance from the central line of $\sim$20 km,

$$\Delta \ll \frac{2\Delta t^*}{\Delta t_0} |\eta - 1|.$$

During computations, the correction Δ was not taken into account.

In the case of the eclipse under observation, the quantity t^* is not equal to the value Δt, placed in Table 4. In the given case the

TABLE 4

λ, см	Contact II		Contact III	
	$t_{II\,p}$	Δt_{II}	$t_{III\,p}$	Δt_{III}
2,0	$19^h14^m58^s\!.3$* — —$19^h15^m28^s\!.3$	$<8^s\!.5$	$19^h15^m58^s\!.8 \div 6^s\!.0$	$14^s \pm 6^s\!.5$
3,2	$19^h15^m2^s\!.8 \pm 9^s\!.0$	$4^s\!.0 \pm 9^s\!.5$	$19^h16^m2^s\!.8 \pm 4^s\!.5$	$18^s \pm 5^s\!.0$
4,5	$19^h14^m58^s\!.3 \pm 4^s\!.5$	$8^s\!.5 \pm 5^s\!.0$	$19^h16^m5^s\!.5 \pm 6^s\!.0$	$20^s\!.7 \pm 6^s\!.6$
10,0	—	—	$19^h55^m58^s\!.3 \pm 12^s\!.0$	$13^s\!.5 \pm 13^s\!.0$

radius of the Moon had an intermediate value between the optical and the radioradii of the Sun ($r_p > r_☾ > r_\odot$). At such a correlation, as is not difficult to obtain from geometric constructions, the second radiocontact was materialized on the W-limb of the solar disk, the second optical contact on the E-edge, the third optical contact on the W-edge and the third radiocontact on the E-edge, and therefore, the quantity $\Delta t^* = \Delta t + \Delta t_0$, where $\Delta t_0 = 38^s \pm 0^s\!.3$, must be substituted in the formula for $\frac{r_p}{r_\odot}$.

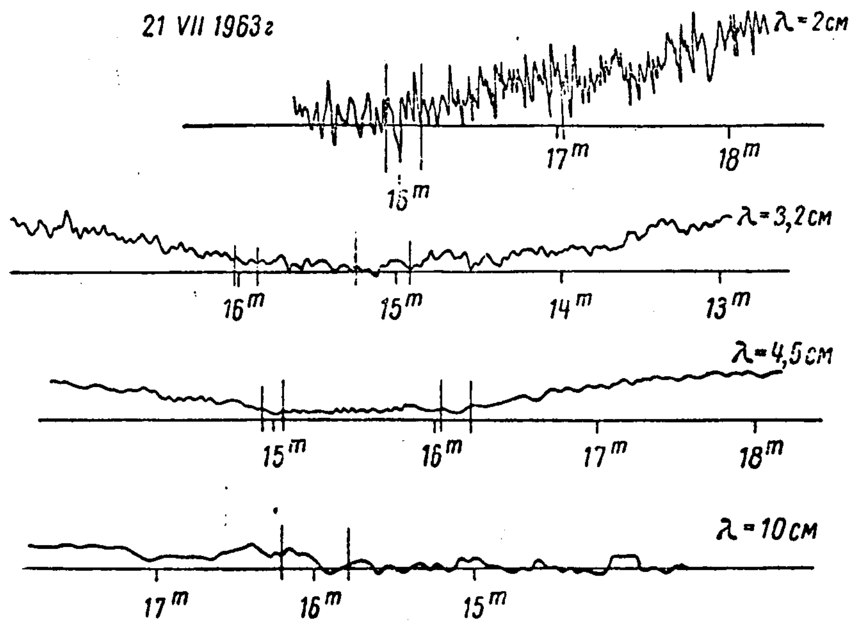

Fig. 2

The results of completed computations are compiled in Table 5 hereafter.

TABLE 5

λ, см	$r_p/r_\odot$		α°	
	E - edge of disk	W - edge of disk	E - edge	W - edge
2,0	1,030±0,005	1,026	~70	—
3,2	1,031±0,003	1,024±0,005	~55	~85
4,5	1,033±0,004	1,026±0,003	~60	~60
10,0	1,028±0,008	—	~90	—

Compiled in this table also are the values of the central angle α, formed by two radii, drawn from the center of the solar disk to intersection points of solar and lunar disk edges (when the centers of both disks do not coincide). The radioradius' values, brought out, constitute quantities, averaged by the arc of solar disk edge, equal to α:

../..

$$\alpha \cong 2 \arccos \frac{\left(\frac{r_p}{r_\odot} - \eta\right)\left(1 + \frac{\Delta r_p}{r_p}\right)}{\frac{r_p}{r_\odot} - \eta + \frac{\Delta r_p}{r_\odot}}.$$

For the sake of clarity, the results of determination of r_p are shown in Fig. 3.

Attention is drawn by the small dependence of the radioradius, determined by the contact II and III, on the wavelength in the entire waveband utilized, which corroborates the assumption of the existence of a region with $r_p =$ const., made in [4].

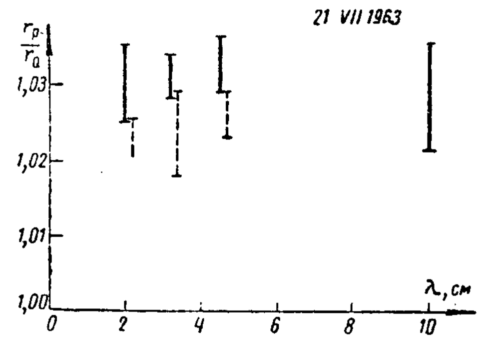

Fig. 3

c) Residual Emission Fluxes from the Concealed Sun

The results of measurement of the residual flux of solar radio-emission are compiled in Table 6, where both, the found values F^*_{res} directly from the recordings, and the corrected valuez F_{res}, by way of accounting the absorption, the natural radiation of the terrestrial atmosphere, the Moon's radio emission equal to 1.4%, and 1% of emission of the open Sun, respectively in $\lambda = 3.2$ cm, 4.5 cm. The effective temperature of Moon's emission was borrowed from [5]. For the computation of the absolute value of residual fluxes, we utilized the results of routine observations of Sun's radio emission in $\lambda = 3.2$ cm and $\lambda = 7.5$ cm [6].

TABLE 6

λ, см	3,2	4,5
F^*_{res}	10	6
F_{res}	4,6	5,3
F_{res} 10^{22} w/m^2 cps	10,7	8,5

The above values of corrected residual fluxes F_{res} are beset with significant errors because of strong influence of atmosphere radio emission during the total phase.

d) Characteristics of Radio Emission Source

During observations in 4, 5 and 10 cm waves,we registered the emission of an opening local source on the Sun corresponding to sunspot group No. 76 (see above). The radioastronomical data of that source observation (contact times and values of the radiation flux F), found from the obtained recordings, are compiled in Table 7 hereafter:

TABLE 7

λ, см	t_{I}	t_{II}	F_u, %	$F_u \cdot 10^{+22}$, $\frac{вт}{м^2 гц}$
3,2	—	—	< 1,5	< 3,4
4,5	$20^h06^m27^s \pm 10^s$	$20^h08^m85^s \pm 7^s$	3,0÷4,5	4,8÷7,2
10,0	$20^h06^m53^s \pm 7^s$	—	2,0÷3,0	1,1÷2,5

It may be seen from the table, that the contact with the source is observed at shorter wavelengths than before, rather than on longer ones, even taking into account the possible error in the determination of times of these contacts.

Introducing the assumption that the effective emission centers in both wavelengths are on a unique radius (drawn from the center of the Sun), it is possible to estimate the difference in height of the effective emission centers Δh by the shift, referred-to above, and the known relative velocity of lunar disk's edge. This difference was found to be within the limits from 7 000 to 20 000 km.

The size of the source and the direction of motion of lunar disk's edge was 1.5'± 0.3', according to measurements in the 4.5 cm wavelength.

The absolute values of source's emission fluxes, compiled in the table, were obtained by utilizing the routine observations of the Toyokawa station, referred-to above. It is not difficult to notice that the spectrum of the source has a maximum, for the excess in flux values at $\lambda = 4.5$ cm over those at $\lambda = 3.2$ cm and $\lambda = 10$ cm, is, a priori, beyond the limits of measurement errors.

In connection with this, it is interesting to bring forth the results of measurements obtained for the same source on radiotelescopes with a great angular resolution* :

$$\left\{\begin{array}{l} F_{н} \approx 2{,}8\% \left(\sim 4{,}3\cdot 10^{-22} \ \frac{watt}{m^2 cps}\right) \text{ at } \lambda = 4.5 \text{ cm and} \\ F_{н} \approx 2{,}4\% \left(\sim 2{,}3\cdot 10^{-22} \ \frac{watt}{m^2 cps}\right) \text{ at } \lambda = 6.6 \text{ cm (SAO of USSR A.Sc.)}; \end{array}\right.$$

$$\left\{\begin{array}{l} F_{н} \approx 1\% \left(\sim 2{,}3\cdot 10^{-22} \ \frac{watt}{m^2 cps}\right) \text{ at } \lambda = 3.2 \text{ cm and} \\ F_{н} \cong 2{,}8\% \left(\sim 2{,}4\cdot 10^{-22} \ \frac{watt}{m^2 cps}\right) \text{ at } \lambda = 7.5 \text{ cm (Toyokawa, Japan)}; \end{array}\right.$$

$$F_{н} = 3{,}1\% \left(\sim 2{,}3\cdot 10^{-22} \cdot \frac{watt}{m^2 cps}\right) \text{ at } \lambda = 9.1 \text{ cm (Stanford, U.S.A.)}.$$

These results corroborate the above conclusion of the presence of a maximum in the emission spectrum of the source observed during the eclipse.

CONCLUSIONS

The above results of preliminary processing of materials obtained during the observations of the solar eclipse of 21 July 1963, allow the following conclusions :

1. - The Sun's radiodiameter, determined by contacts II and III in the wavelength range from $\lambda = 2$ to $\lambda = 10$ cm, depended little on wavelength.

2.- The spectrum of the radio emission source, found above a small sunspot group, had a maximum in the region between $\lambda = 3.2$ cm and $\lambda = 10$ cm.

In conclusion, the authors express their sincere gratitude to A. A. Zorin, I. I. Tkachenko, E. F. Puzin, who helped to prepare the expedition of the radioastronomical group to Simushir Island.

**** THE END ****

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